

# Trace Explosive Detection Challenges for Transportation Security

HSARPA Workshop

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Security  
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# Transportation Security Administration

## Transportation Security Laboratory

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# Department of Homeland Security DHS

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graph TD; DHS[Department of Homeland Security DHS] --> BTS[Border & Transportation Security (BTS)]; BTS --> TSA[Transportation Security Administration (TSA)]; TSA --> NTS[National Transportation System Security Plan]; NTS --> Rail[Rail]; NTS --> Maritime[Maritime]; NTS --> Transit[Transit]; NTS --> Pipeline[Pipeline]; NTS --> Aviation[Aviation]; NTS --> Highway[Highway];
```

**Border & Transportation  
Security  
(BTS)**

**Transportation  
Security Administration  
(TSA)**

**National Transportation System Security Plan**

**Rail**

**Maritime**

**Transit**

**Pipeline**

**Aviation**

**Highway**



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# Security Challenge

## Mission

- The Office of Security Technology will develop and implement the best security technology solutions to protect the nation's transportation systems, ensuring freedom of movement for people and commerce.

## Transportation Systems

- |            |          |
|------------|----------|
| ▪ Aviation | Pipeline |
| ▪ Highway  | Railway  |
| ▪ Maritime | Transit  |



# Domain Awareness

- **What are we trying to protect?**

- People
- Cargo (checked and carry-on baggage and commercial shipments)
- Conveyance
- Facilities

- **What are we trying to protect against?**

- Explosives Radiological/Nuclear
- Weapons
- Unauthorized Access
- Chemical/Biological/Agents



# Technology Requirements

- Very Low False Alarm Rate
- Very High Probability of Detection
- Integrated Element, Holistic Security Infrastructure
- Minimal Decision Making by Human
- Automated
- Robust
- Can Be Operated by Screeners
- Not Too Expensive
- Privacy Concerns Addressed



# Where we are:

## Equipment Deployment

**ATSA Requirement: All checked bags must be screened by Explosive Detection Systems (EDS) or EDS-equivalent by December 31, 2002**

- Deployed the following to airports throughout the country:
  - 1733 Enhanced Walk Through Metal Detectors (EWTMD)
  - 1392 Threat Image Projection (TIP) ready X-ray machines
  - 1161 Explosive Detection Systems (EDS)
  - 6595 Explosive Trace Detection (ETD) Units



# Enabling Technologies

- Access Control
- Communications
- Bulk (Explosive) Detection
- **Trace (Explosive) Detection**
- Human Factors
- Aircraft or Conveyance Hardening



# Explosives and Weapons Detection

## ‘Bulk and Trace’ Programs



← Bulk →



← Trace →

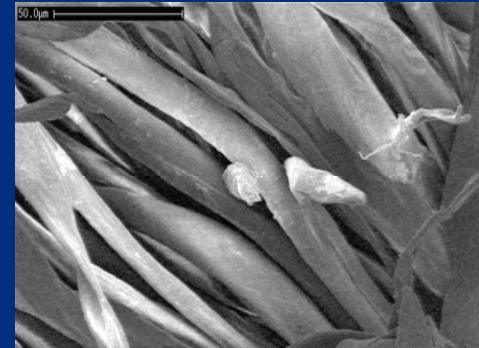


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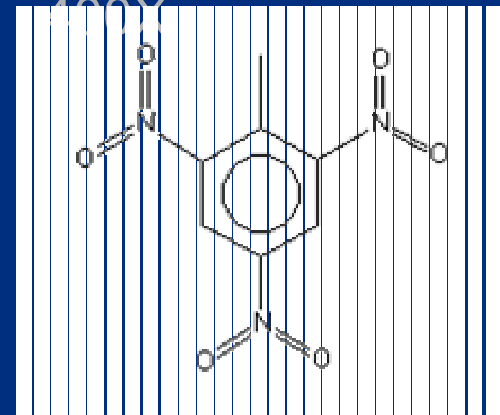
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# Trace Detection ←



C-4 particle on cloth at  
100X



Vapor molecule of TNT

## Trace Program:

- Explosives
- Chemical Agents
- Biological Agents



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# EXPLOSIVE TRACE DETECTORS

- Can detect & identify microscopic amounts of explosive material
- Used for detection of the explosive component of an IED
- Used in conjunction with X-Ray and physical search to provide an additional layer of security
- ETD alarm does not necessarily mean there is an IED in the bag
  - Passenger carrying certain medications
  - Fertilizers/high nitrogen levels



# Deployed Trace Detectors

- BARRINGER
  - Technology - Ion Mobility Spectrometry
  - Approved models - IonScan Models 400 and 400B
- IONTRACK
  - Technology - Ion Mobility Spectrometry
  - Approved models - Itemizer-DOS & Itemizer-W
- THERMODETECTION
  - Technology - GC/Chemiluminescence
  - Approved models - EGIS Models 3000 & II



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# Trace Detection

- Why do Trace Detection
- What are we detecting
- Where are the Traces
- How do you collect them
- What Next???



# Why do Trace

- Only way to screen people for explosives
- Available sample is independent of the size of the bomb (good and bad news)
- Instruments are inexpensive and safe
- Nuisance alarm rate is low
- There will always be a sample ???



# Trace Detection

- Collect
- Separate
- Detect
- Residues or vapors of explosives
- Optically View or Activate Traces



# What have we learned?

- Nuisance alarms
  - Manageable
  - Reproducible
  - Resolvable
- Operationally Viable



# Trace Explosive Detection

- Ion Mobility Spectrometry

- Chemiluminescence

Mass Spectrometry

- Canine Olfaction

Antibodies

Optical Techniques



# Not Changed since last ICAO Workshop

- Sampling techniques
  - Inefficient
  - Ineffective
- Detection Technology



# What are we Detecting?

Fortuitous Contamination

Or

Reliable Indications

- Policy makers are concerned



# Where are the traces?

About where you would expect them to be.



# How do you collect them?

The unsolved problem -

- Rubbing
- Wiping
- Air Flow
- Optical - detect in place



# Explosives

## Standard Explosives

- ❖ TNT
- ❖ RDX
- ❖ PETN
- ❖ Nitroglycerin (NG)
- ❖ Ethylene Glycol Dinitrate (EGDN)

## Plastic Explosives

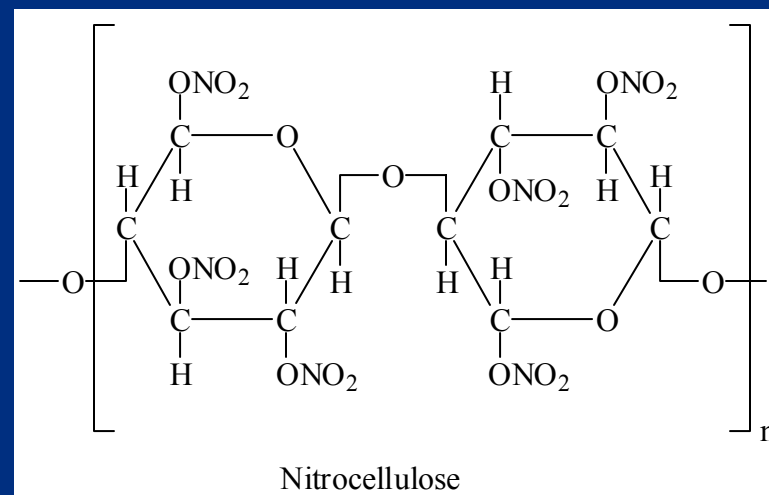
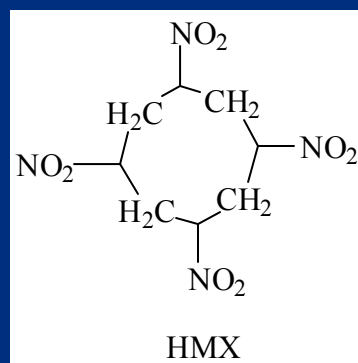
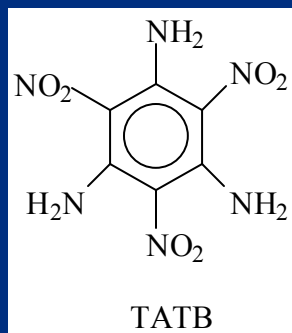
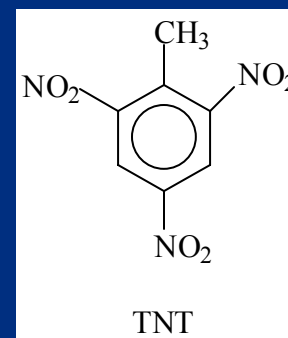
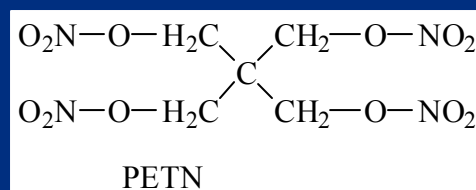
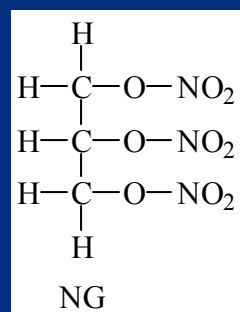
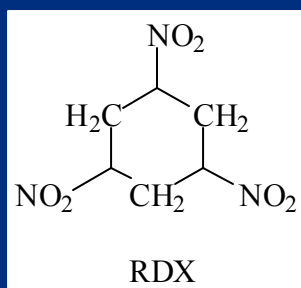
- ❖ C-4 (RDX)
- ❖ Detasheet (PETN)
- ❖ Semtex (RDX + PETN)

## Improvised Explosives

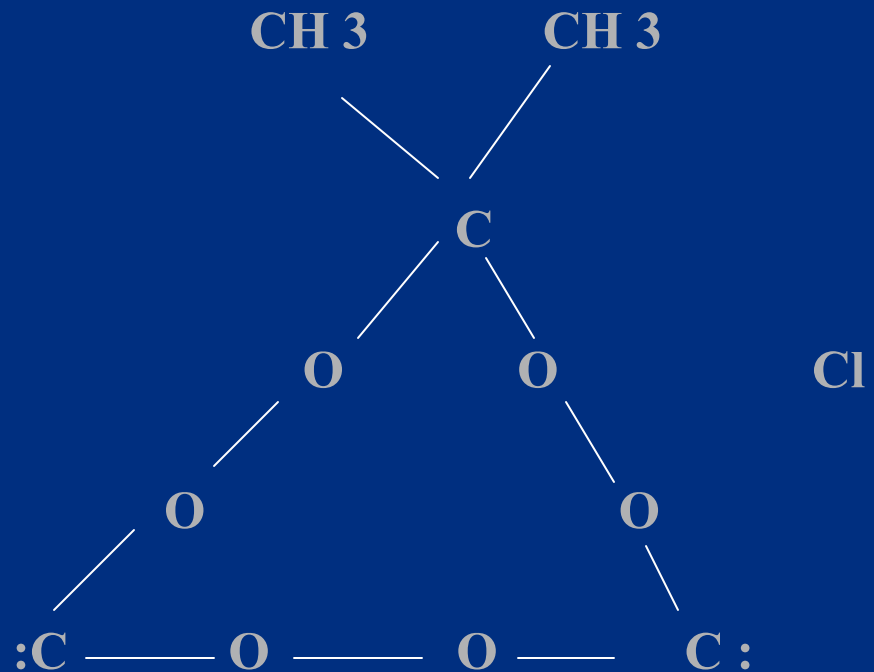
- ❖ ANFO (Ammonium nitrate + fuel oil)
- ❖ Urea nitrate
- ❖ Triacetone triperoxide (TATP)



# Explosive Compounds



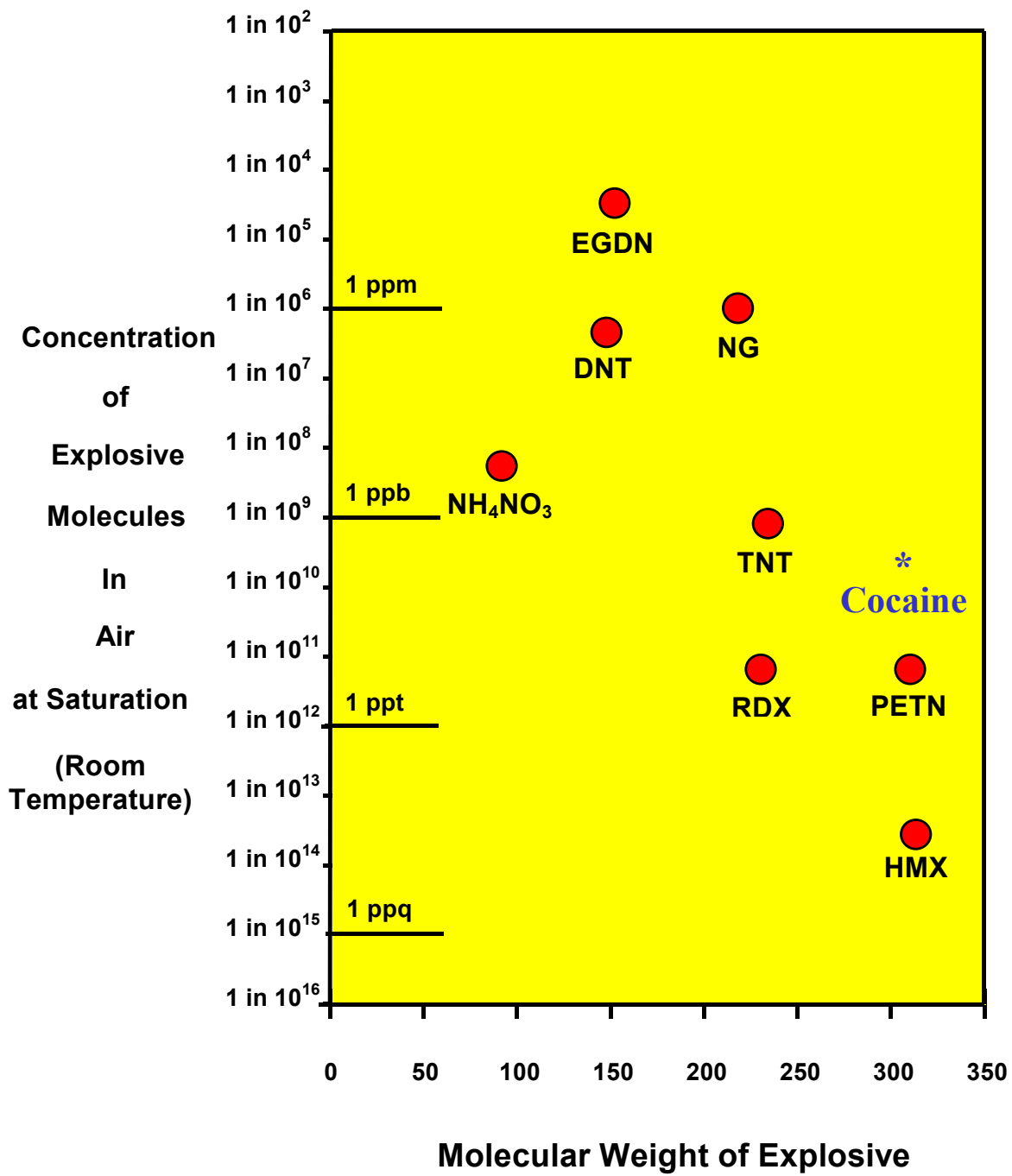
# Triacetone triperoxide



Name	Common Name	Molecular Weight
Nitroglycerine	NG	227
Pentaerythritol tetranitrate	PETN	316
Nitrocellulose (structural unit)		324 +%N
Hexogen	RDX	222
Octogen	HMX	296
Trinitrotoluene	TNT	227
1,3,5-triamino-2,4,6-trinitrobenzene	TATB	258



Ref: US DOE Study



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# Tagging of Explosives

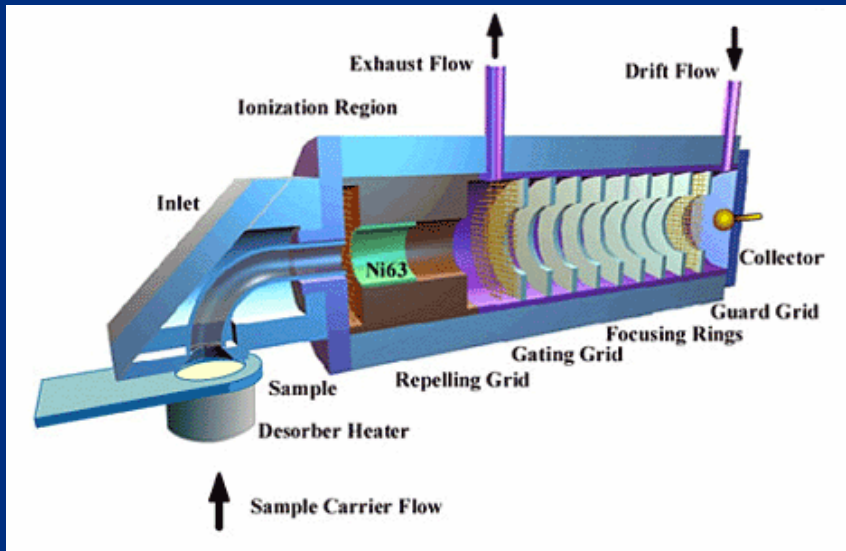
The International Civil Aviation Organization (ICAO) has mandated that volatile taggants be added to plastic explosives during their manufacture, in order to facilitate the detection of these explosives. Four taggants were recommended:

<i>Taggant</i>	<i>State (at 25° C)</i>	<i>Vapor pressure at 25° C [torr]</i>
EGDN	liquid	0.006
DMNB	solid	$1.67 \times 10^{-3}$
o-MNT	liquid	0.11
p-MNT	solid	0.03

2,3-dimethyl-2,3-dinitrobutane (DMNB) seems to be the preferred one.



# ION MOBILITY SPECTROSCOPY (IMS)



- Substrate heated to vaporize particles
- Molecules are ionized by a weak radioactive source and drift through a weak electric field
- Particle time of flight is a distinct fingerprint, enabling detection

## Applications:

- Explosives detection on both luggage and people
- Detection of narcotics
- Detection of narcotics

## Technical Barriers:

- Dependent on screener sampling
- Susceptible to atmospheric changes
- Calibration requirements
- Saturation possible



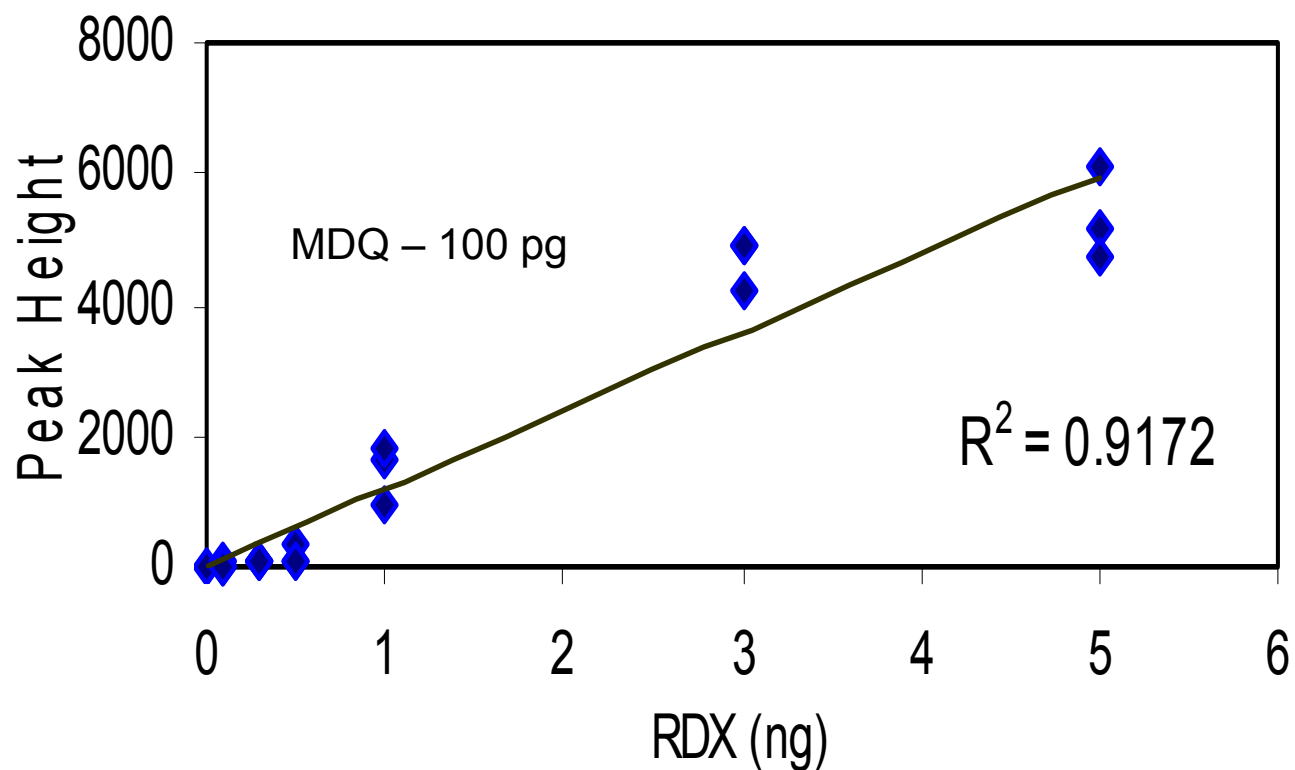
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# RDX Response Curve



# Explosives Detection Methods

## People

- Emerging Technologies
  - Explosives Screening of passengers using trace portals
  - Imaging Technologies



Walk through trace explosives detection portal

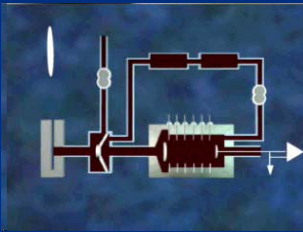


# The science and engineering behind the EntryScan...

## The Science ...

- Aerodynamic Sample Collection
- Trace Detection / Identification

### The ITMS Detector



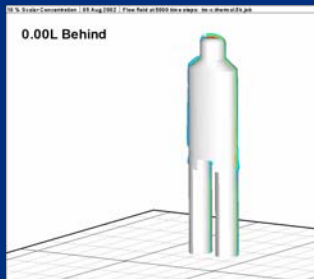
—A New Hypothesis

## Reynolds Averaged Navier-Stokes

$$\frac{\partial U_i}{\partial x_i} = 0$$

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{\partial \hat{p}}{\partial x_i} + \frac{1}{Re} \frac{\partial^2 U_i}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j} \overline{u_i u_j} + \delta_{i3} \frac{Gr}{Re^2} \Theta$$

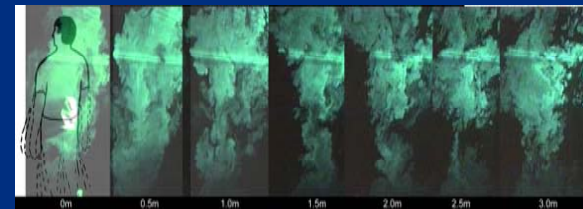
## Scalar Flow Model



## Human Convection Plume



## Laser Sheet Flow Visualization

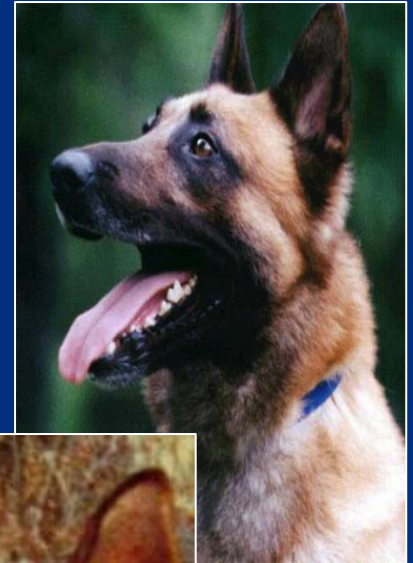


# What analyte is a detection dog signaling on?



# Research and Development

- R&D Efforts
  - Determine detection odor signatures
  - Determine canine “detection limits”
  - Development of simulants and training aids
  - Generalization to Other Explosives
    - Single Odor or “Bouquet”
  - Dog Selection/Breeding
  - Impact of Cross-Contamination
  - Field Test Kit - “Push-to-Test”



# Partnerships

- TSWG
- Office of Special Technology
- U.S. Secret Service
- DARPA
- DoD Military Working Dog Program
- UK
- ONDCP
- Bureau of Alcohol Tobacco & Firearms (BATF)



# Semtex H Ingredients

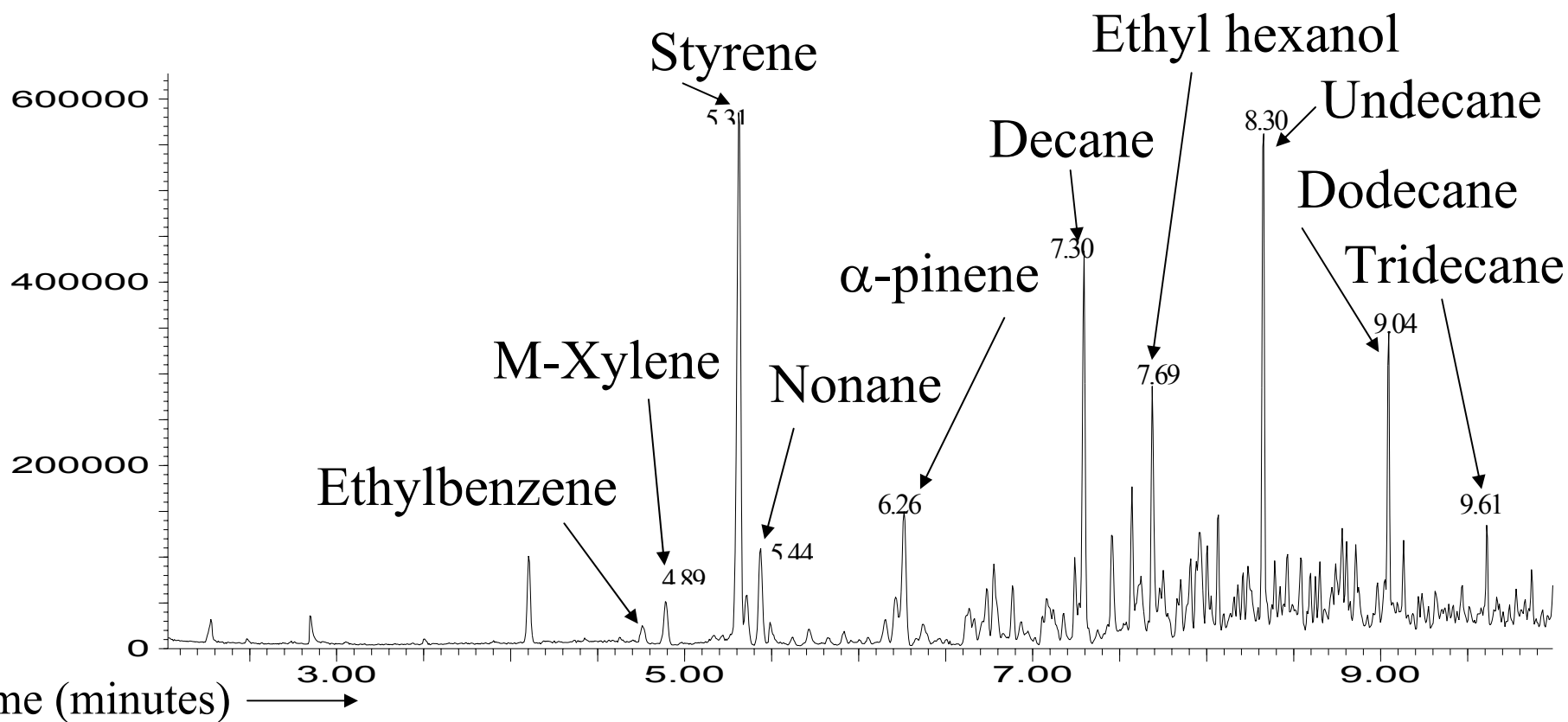
- Ingredients:
  - 35% +/- 3% PETN
  - 50% +/- 3% RDX
  - 15% +/- 2% Butadiene-styrene + oil
  - 0.1% minimum DMNB



# Semtex H Headspace Analysis

Abundance

TIC: SEMTA31.D



# Vapor Pressures at 25°C (Semtex H)

## ■ Headspace Components

- Ethylbenzene ~ 9.6 torr
- m-Xylene ~ 8.5 torr
- Styrene ~ 6.1 torr
- Nonane ~ 4.3 torr
- $\alpha$ -pinene ~ 4.4 torr
- Decane ~ 1.3 torr
- Ethyl hexanol ~  $1.4 \times 10^{-1}$  torr
- Undecane ~  $3.9 \times 10^{-1}$  torr
- Dodecane ~  $1.2 \times 10^{-1}$  torr
- Tridecane ~  $3.8 \times 10^{-2}$  torr

## ■ Energetic Components

- PETN ~  $1.4 \times 10^{-8}$  torr
- RDX ~  $2.6 \times 10^{-9}$  torr
- DMNB ~  $2.0 \times 10^{-3}$  torr



# TNT Headpace Major Constituents and Abundance

2,4-dinitrotoluene = 62% (v.p.  $\sim 2.3 \times 10^{-4}$  torr)

1,3-dinitrobenzene = 16% (v.p.  $\sim 3.9 \times 10^{-3}$  torr)

3,5-dinitrotoluene = 10% (v.p.  $\sim 1.5 \times 10^{-4}$  torr)

1,4-dinitrobenzene = 6%

trinitrotoluene = 3% (v.p.  $\sim 5.9 \times 10^{-4}$  torr)

1,2-dinitrobenzene = 2%



# IBDS, Auburn University

## Substance Sensitivities

- NG, Cyclohexanone, DMNB

## Detection Odor Signatures

- NG Smokeless Powder, C4, AN Dynamite, TNT, ANFO

## Generalization

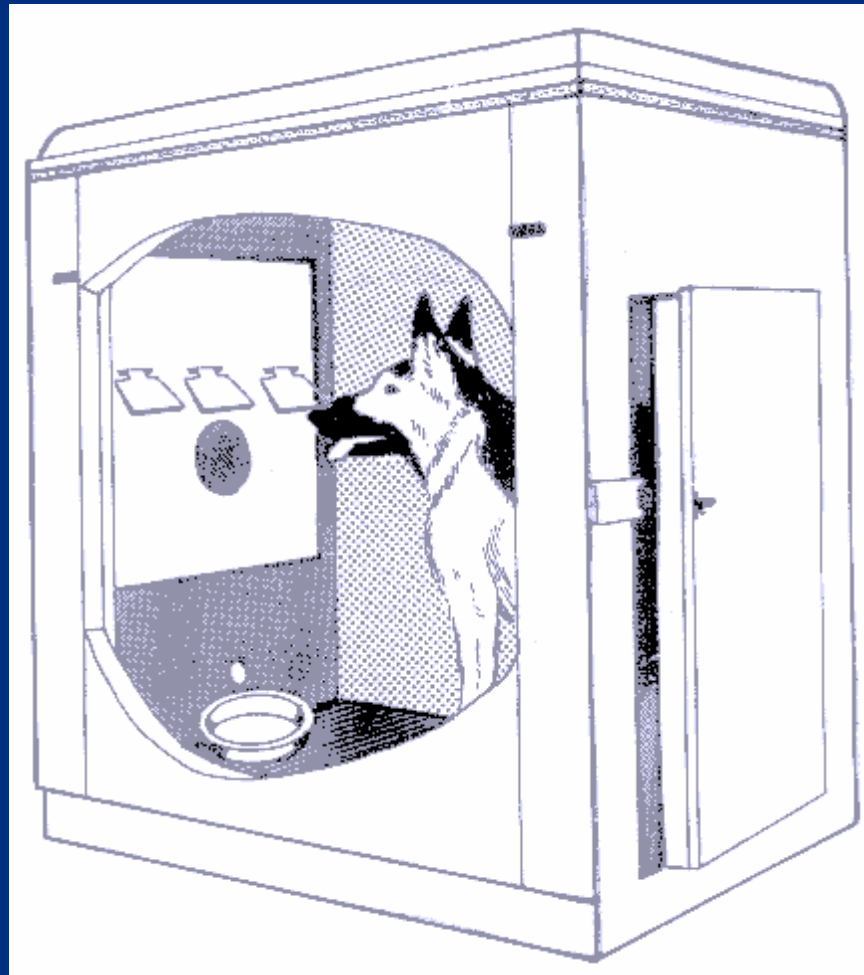


# Major Constituents and Abundance of Targets

- NG Smokeless Powder
  - acetone = 81%
  - toluene = 12%
  - nitroglycerine = 7%
  - limonene = < 1%
- C4
  - cyclohexanone = 76%
  - toluene = 7%
  - 2-ethyl-1-hexanol = 5%
- TNT
  - 2,4-dinitrotoluene = 62%
  - 1,3-dinitrobenzene = 16%
  - 3,5-dinitrotoluene = 10%
  - 1,4-dinitrotoluene = 6%
  - trinitrotoluene = 3%
  - 1,2-dinitrobenzene = 2%
- AN Dynamite
  - ethylene glycol dinitrate
  - ammonium nitrate

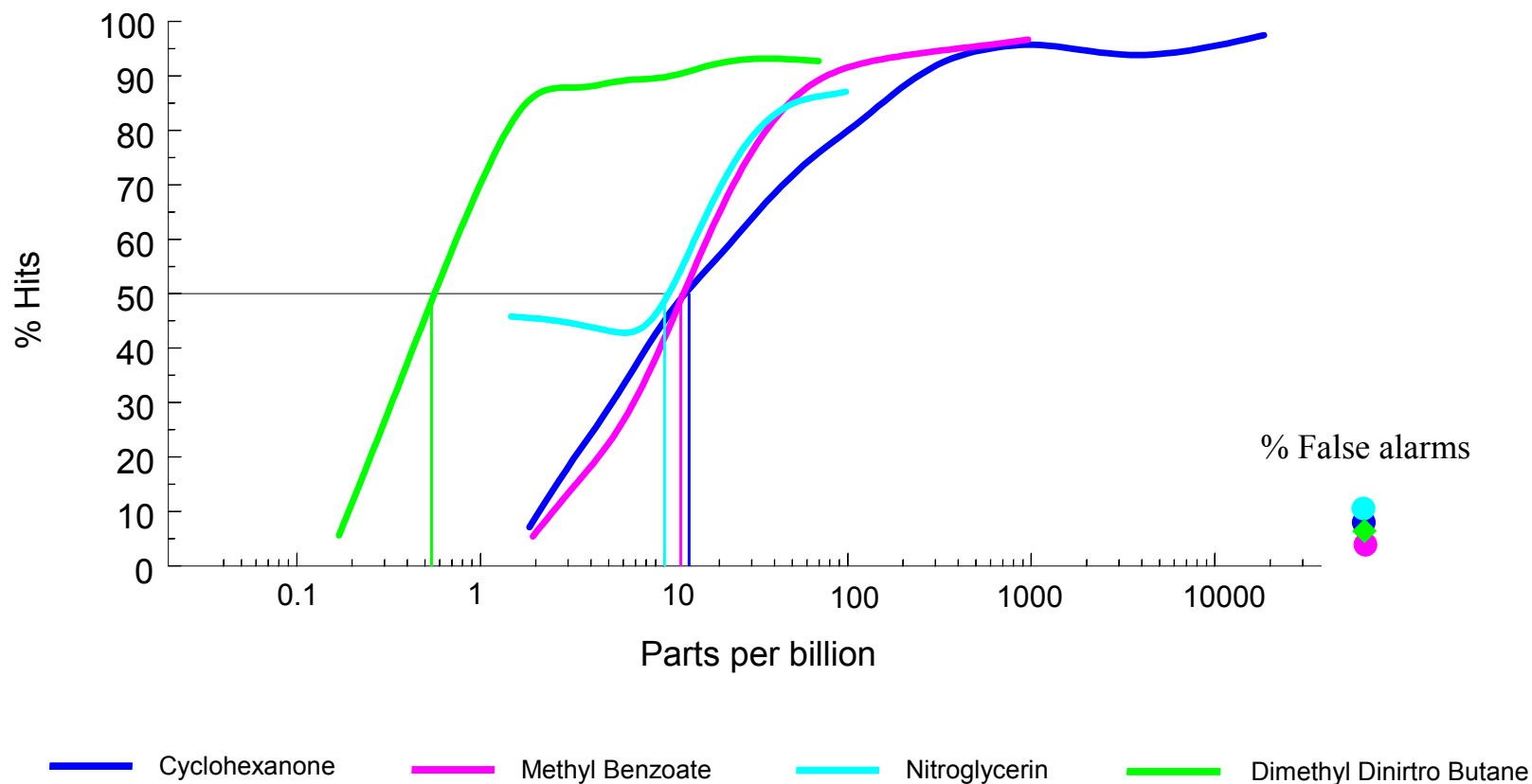


# Olfactometer (vapor generator)



# Olfactory Sensitivity

## Canine Olfactory Detection Functions



# TNT Signature Response Summary

Dogs

<u>Constituent(s)</u>	<u>6241</u>	<u>6561</u>	<u>6783</u>	<u>7819</u>	<u>7001</u>
2,4 DNT	X	X	X	X	
1,3 DNB	X			X	
DNT/DNB	X			X	



# Signature Response Summary

## ■ TNT

Constituent(s)	Dogs				
	6241	6561	6783	7819	7001
2,4 DNT	X	X	X	X	
1,3 DNB	X			X	
DNT/DNB	X			X	

## ■ C4

Constituent(s)	Dogs			
	5174	6548	7007	6382
Cyclohexanone	X		X	
2-ethyl-1-hexanol	X	X		



# Signature Response Summary

## ■ Dynamite

Constituent(s)	Dogs			
	5174	6548	6382	7007
EGDN			X	
Ammonium Nitrate		X		
EGDN/Ammonium Nitrate	X			

## ■ Smokeless Powder (Hercules Unique)

Constituent(s)	Dogs		
	5174	7007	6382
Acetone	X	X	
Limonene		X	
Acetone/Limonene		X	
Acetone/Toluene/Limonene	X	X	X



# Conclusions

- Signature is often multi-component, most volatile components of explosive
- Detection thresholds
  - DMNB ~ 0.550 ppb
  - others ~10 ppb
- different dogs cue on different things
- concentration is always a factor in training dogs
- Dogs, some better than others, can generalize odors



# Acknowledgements

- Virginia Polytechnic Institute and Galaxy Scientific Corporation
  - Semtex H headspace data
- Aerodyne Research
  - Vapor Pressure Data
- Auburn University
  - TNT headspace and canine data



# Explosive Trace Detectors The Future ...



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# Miniaturized Explosives Detection Systems



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# Explosives/Chemical Detection Systems

**Present**



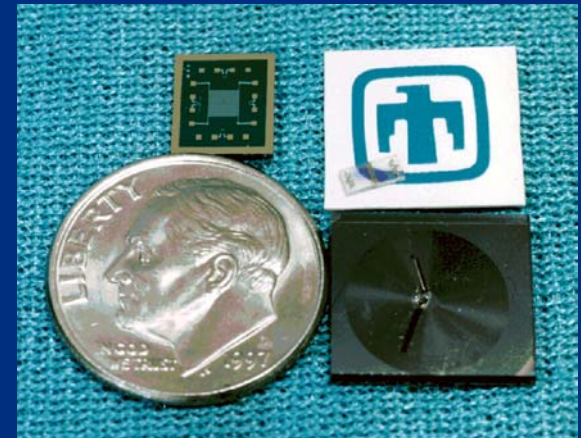
**Trace Portal**  
~ \$120k

**Near-Term 2-3 Year**



**Portable  
Raman uProbe**  
~ \$25k

**Future ~ 5yr.+**



**MEMS Array Sensor**  
< \$1k



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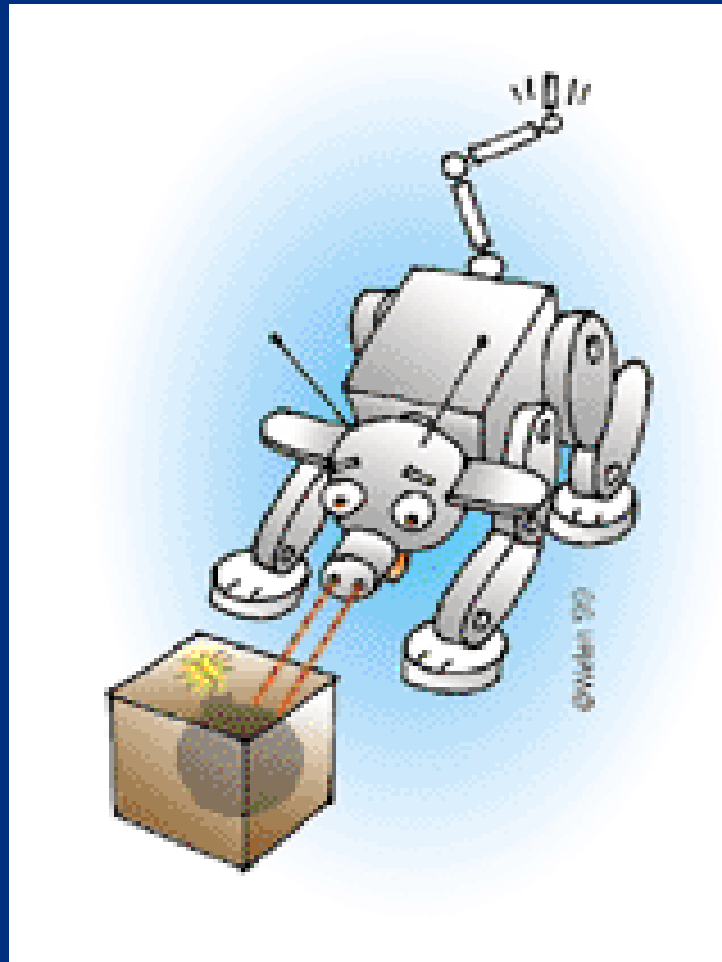
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# Electronic Noses

## *The desired solution*

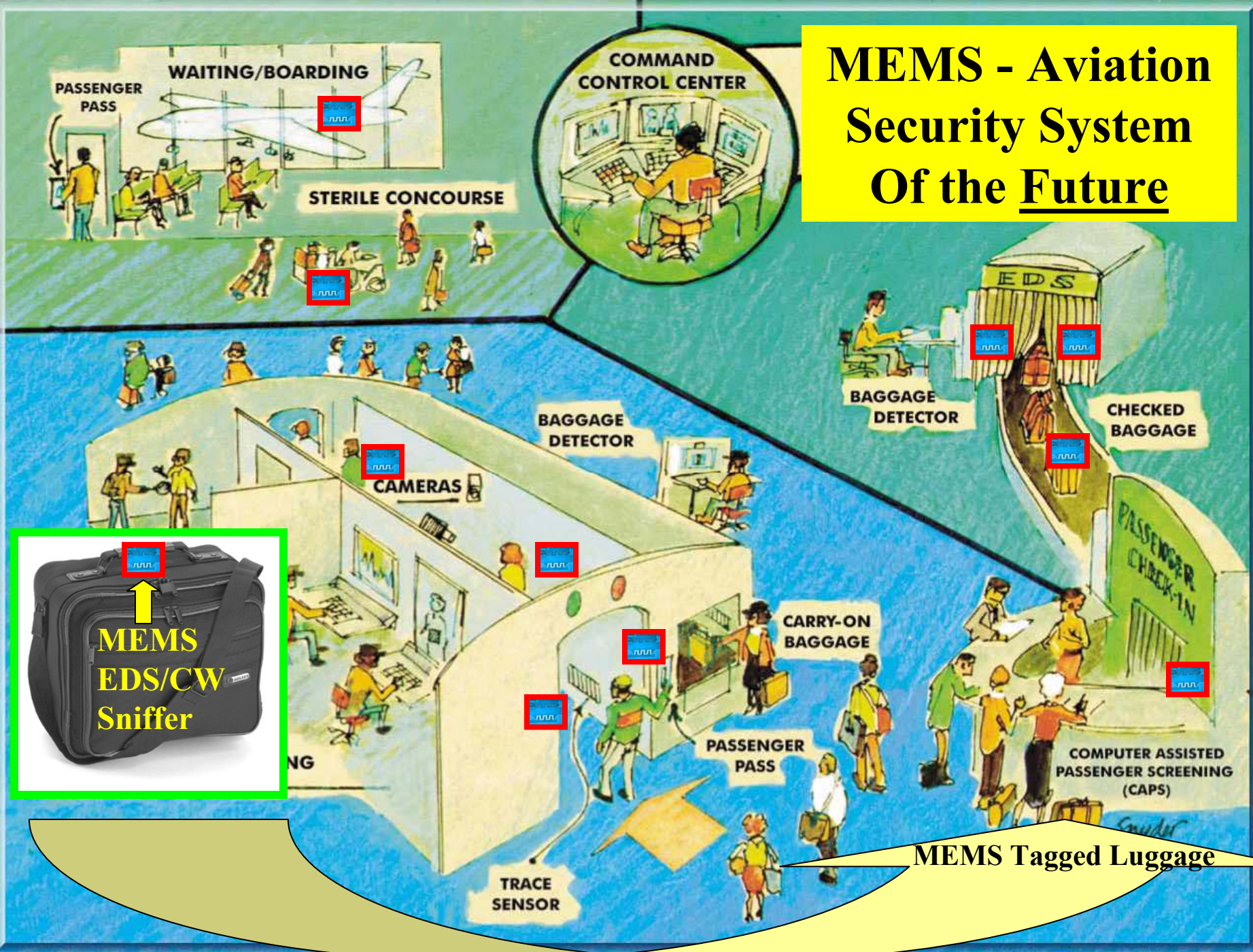


# Obstacles to Overcome

- ❖ Minute quantities of explosive available
- ❖ Different types of explosives
- ❖ Vapors of volatile explosives or typical ingredients
- ❖ Vapors condensed on dust
- ❖ Particulates bound to surfaces
- ❖ Collect particulates efficiently and move to detector



# MEMS - Aviation Security System Of the Future





# Future Prospects

- ❑ Microsensors/electronic noses will replace existing vapor & trace detectors (IMS, TEA, MS).
- ❑ Nanotechnology will become the major technology of microsensors.



# Questions?

